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TOWARDS INCORPORATING UNCERTAINTIES IN A 3D GEOTECHNICAL MODEL OF THE LOWER VAR VALLEY, NICE

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Accurate 3D geotechnical models of valleys are essential for seismic numerical simulations of site amplifications. Although many sources of uncertainty are present, these are rarely quantified and presented in final models. To address this, we incorporate uncertainty using 2D random field samples from the geophysical measurements of fundamental resonance frequency (f_0) applying Bayesian compressive sampling and Karhunen–Loève expansion.

The Lower Var Valley, between Nice and Saint-Laurent-du-Var, is a 2 km wide fluvial sedimentary basin where site effects have been observed in earthquake recordings. This seismically active area has a reference peak ground acceleration on rock of 1.6 m/s², per French seismic regulations. The valley consists of recent alluvial deposits overlying Pliocene delta conglomerates, sloping 15–20° southward. Quaternary sediments reach depths of 100 m at the Var estuary. The existent 3D geological model used borehole log data (335 logs, only 28 reaching substratum) and geophysical measurements of fundamental resonance frequency (f_0) from 355 ambient vibration recordings.

In this paper, we first quantify the differences between the f_0 from the existing model and those from the geophysical measurements (355 ambient vibration recordings). We derive a random field of f_0 using the Bayesian compressive sensing – Karhunen-Loève expansion (BCS-KL) method on the f_0 from the measurements. The proposed random filed model of f_0 accurately represents the measurements, with the definition of the related uncertainties quantified in terms of the coefficient of correlation. Our results are refine previous models and will support future 3D numerical simulations and basin site effects analysis.

Keywords: 3D geotechnical model; basin amplification; HVSR; random fields

1. Introduction

The Lower Var Valley (LVV) is of considerable economic importance for the region, housing the prefecture and the international Nice airport, the second largest in France. It constitutes a 2 km wide sedimentary basin where site effects have been observed on seismic recordings (Courboulex et al., 2020). Previous geological studies indicate that the valley is filled with recent alluvial deposits overlying conglomerates from the Pliocene. The sedimentary thickness extends to a depth of approximately 100 meters at the mouth of the Var river (e.g. Courboulex et al., 2020; Dubar, 2012).

Several years of geotechnical and geophysical studies include: 355 ambient vibration measurements conducted in the LVV by Rohmer et al. (2020) and previous studies for seismic microzonation (Régnier et al., 2020). These measurements were used to estimate the fundamental resonance frequency (f_0) at each measurement point in the sedimentary basin calculating the Horizontal to Vertical spectral ratio (HVSR). It include also 335 boreholes that were collected from the French Geological Survey (BRGM) database and from geotechnical surveys provided by the city of Nice. Most of them are located in the southern part of the valley. Only 23 boreholes reach the engineering bedrock bringing punctual, but strong, constraints to the basin thickness. However, a large uncertainty exists on the basin geometry for the entire valley.

These various data were combined in a geomodeler software and used by Rohmer et al. (2020) to establish a multi-layered 3D geological model of the valley. It includes the definition of the elastic properties of the soil (the shear wave velocity and density) and the geometry of the basin. The average shear wave velocity (Vs_{mean}) in the alluvium varies from 100 m/s at the edge to 600 m/s in the center of the valley. However, the authors mention that the uncertainties linked to the geometry and properties of the soil are still not well defined. The main objective of this work is to refine the current model by including the uncertainties related to the spatial variability of the available data. This paper focuses on the first part, which is the definition of the random fields of fundamental resonance frequency f_0. This is a key parameter for site response analysis and can be further used to assess the random fields of seismic substratum depth.

2. Incorporating spatial variability with random field generation

The spatial variability of the in-situ data is usually described in terms of mean value, coefficient of variation, correlation function and scale of fluctuation. A lot of measures are needed to accurately measure these parameters, specially the last two. In the present study, the Bayesian compressive sensing – Karhunen Loève expansion (BCS-KL) method presented by Montoya-Noguera et al. (2019) is used. The BCS-KL method is able to quantify the statistical uncertainty of spatially varying data and generate random fields of these data. Similiar to the Kriging method , the BCS-KL method captures the best estimate and confidence interval. In contrast, the BCS-KL bypasses the need to assume stationarity and correlation functions as it is non-parametric and data-driven.

3. Results

3.1. *Differences between existing model and measurements*

First, the comparison between the f_{0-num} calculated in this study using Haskell-Thomson method with the 1D soil columns from the existing model and the f_0 from measurements is shown in Fig. 1. The map of f_0 reveals the spatial distribution of resonance frequencies across the study area (Fig. 1a). Higher values of f_0 are observed in regions with shallower sedimentary cover, while lower values indicate thicker deposits. However, these values could also be influenced by higher or lower Vs, and a combination of both factors. In Fig. 1b, the obtained f_{0-num} values exhibit a similar pattern. A comparison between the HVSR-derived f_0 and the calculated values f_{0-num} (Fig. 1c) highlights key discrepancies at the borders of the basin that correspond to 10 % of data. In addition, localized deviations are observed, particularly in areas where complex stratigraphy due to delta depositions influence the results. Excluding these values, the general trend presents average differences of 12 %, with some values below and some above the measured value. These differences indicate potential model refinements, especially in regions where measured f_0 values suggest a different bedrock depth and Vs profile than predicted by the model.

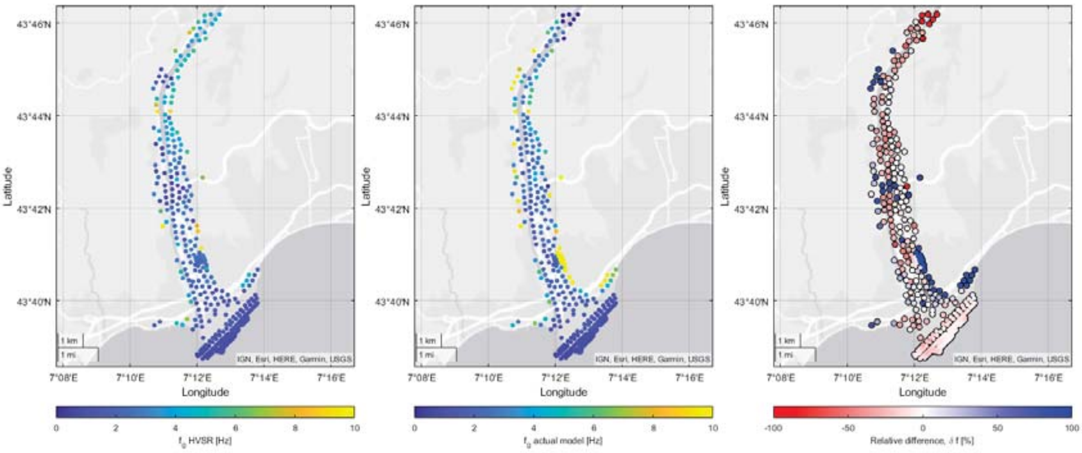

Fig. 1. Maps of(a) f_0 from ambient vibration measurements, (b) f_{0-num} estimated from existing model, and (c) differences between values

3.2. *Obtained Random field samples for f_0*

The mean and coefficient of variation of the random fields of f_0 are shown in Fig. 2. The mean values of f_0 in Fig. 2a range between 0.67 and 10 Hz, with a mean of 1.6 Hz, with decreasing values in the center of the valley and towards the south, denoting an increase in deposit thickness, as expected. The coefficient of variation (CV) in Fig. 2b ranges between 7 and 30 %, with a mean of 15 % but can locally reaches values higher than 50% at the borders of the model, associated with lower constraints at the extremities. When compared with the resonance frequency of the measurements, the relative differences are between ± 20 % for 70 % of the data, except for a few values at the north-south middle of the valley. These locations were also poorly represented by Rohmer's model. Compared to this model, the average random field improves the prediction at the southeast border of the valley with a difference that decreases from 100% to 50%. The main contribution is that it provides a quantification and incorporation of the uncertainties related to the spatial variability of the in-situ data.

4. Conclusion

In this work, we build upon previous research that defined a deterministic 3D model of the Var Valley by incorporating uncertainties. To do so, we defined random fields of the fundamental resonance frequency (f_0) by applying the Bayesian compressive sensing – Karhunen-Loève expansion method to the 355 ambient vibration measurements available in the valley. In addition to quantifying the uncertainty, the proposed model improves the predicted f_0 compared to the initial 3D model, especially at the southeast borders of the valley. This work marks the beginning of an effort to develop a comprehensive 3D model of the Var Valley that accounts for the uncertainties in

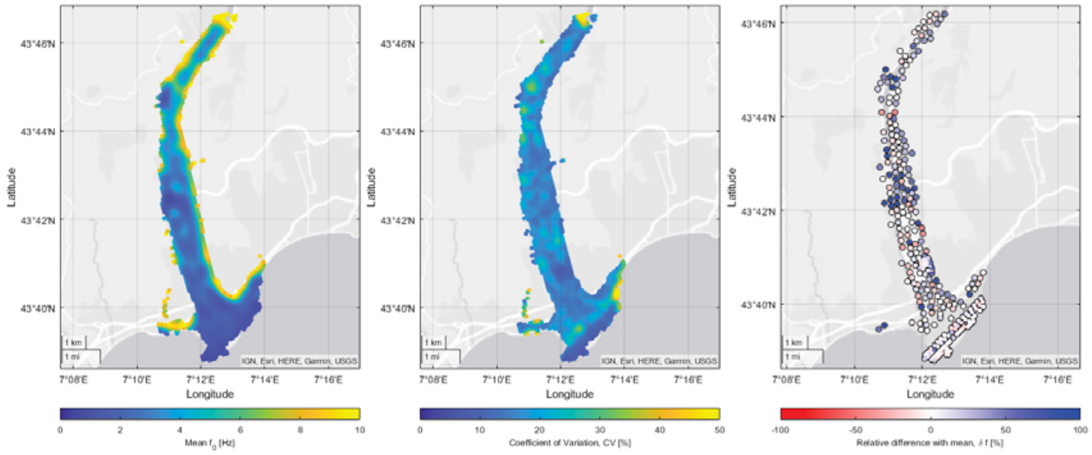

Fig. 2. Random fields obtained from the ambient vibration measurements f_0: (a) mean, (b) coefficient of variation, and (c) differences between mean values and ambient vibration measurements

geometry associated with sparse measurements. Perspectives of work include the use the 28 borehole logs reaching substratum and f_0 values at these sites to invert Vs profiles (average with its standard deviation). Combining these profiles with random fields of f_0, the substratum depth random fields can be defined.

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